eRD14: Photosensors and Electronics

Projects

- Photosensors in High Magnetic Fields (Y. Ilieva, C. Zorn)
- MCP-PMT/LAPPD (J. Xie, M. Chiu)
- Electronics (G. Varner, M. Contalbrigo, I. Mostafanezhad)

High-B Sensor Program
eRD14 FY21 Proposal

Y. Ilieva, B. Moses (USC); T. Cao (UNH); C. Gleason (Indiana U.);
C. Zorn, J. McKisson (JLab); G. Kalicy (CUA); A. Lehmann (FAU),
P. Nadel-Turonski (SB); C. Schwarz, J. Schwiening (GSI); Ch. Hyde (ODU)

Goals

- Identify the limitations of operation of commercially-available MCP-PMTs in high B-fields: $G(B, \theta, \varphi)$, $\sigma_t(B, \theta, \varphi)$
- Optimal location and orientation of sensors in the EIC detector: tilt angle with respect to the local B-field; different sensor options
- Suitable parameters for operations in high magnetic fields: HV

The High-B Facility is located at Jefferson Lab.

Sensors in High-B Fields: FY20

FY20 Planned Activities

- Evaluation of the gain, ion-feedback, and timing resolution of a multi-anode 10-μm pore-size Planacon XP85122-S, HiCE (ALD coated) as a function of (B, θ, φ, HV) (delayed)
- Gain and timing studies of XP85122-S, HiCE with changing $HV_{Cathode\text{-}MCP1}$, $HV_{MCP1\text{-}MCP2}$, $HV_{MCP2\text{-}Anode}$ (delayed)

Reduced funding in FY20: priority given to the procurement of XP85122-S (funds from DIRC rerouted to High-B).

Progress in January 2020 - May 2020

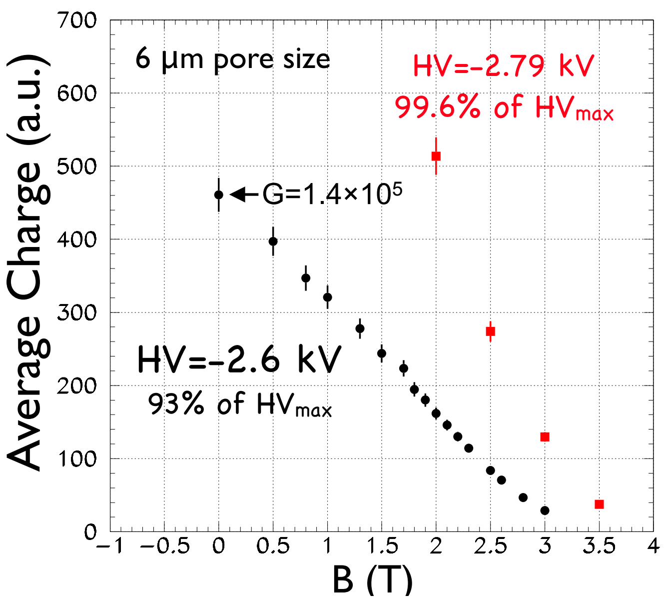
- Purchase of a 32x32 XP85122-S, HiCE Planacon (complete, expected delivery August)
- Preparation of a signal readout of a few channels of XP85122-S at JLab, Samtech connector or Condalign film, new preamp (in progress)
- On-loan agreement with Photek (6-μm pore size) negotiated for December 2020
- USC Magellan scholarship awarded to Benjamin Moses to work on High B at JLab (4-week salary and transportation)

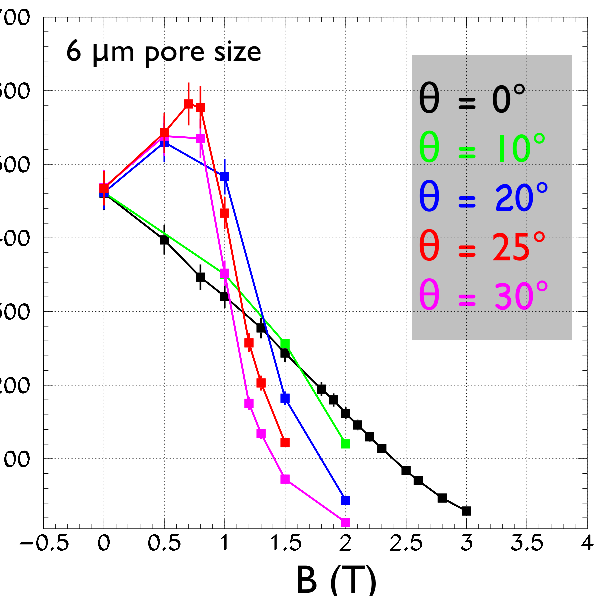
Sensors in High-B Fields: FY21

Proposed FY21 activities

- Full scan of 10-μm XP85122-S, HiCE Planacon: timing, gain, ion feedback (B, HV, θ, φ)
- Studies with changing $HV_{Cathode\text{-}MCP1}$, $HV_{MCP1\text{-}MCP2}$, $HV_{MCP2\text{-}Anode}$
- Full scan of a 6-μm Photek MAPMT253: timing, gain, ion feedback (B, HV, θ, φ)

  Size: 6x6 cm^2. Channels: 16x16. Pixel: 3 mm. A possible alternative to Planacon





B-field performance of Photonis PP0365G .

Our previous studies of single-anode MCP PMTs suggest smaller pore size yields higher-B immunity. Details of performance depend on orientation.

High-B Sensor Activities: FY21

Two cold-magnet runs are needed to characterize XP85122-S, HiCE and MAPMT253.

Scenario assuming normal access to JLab and safe travel situation

- 2 weeks in December 2020
- 3 weeks in Summer 2021

Alternatively

- 3 weeks in Summer 2021, 2 weeks in December 2021

Cold-magnet data taking

- 12 - 14 hour-long daily shifts
- 2 persons per shift
- 3 shifts per day: a group of 6 persons ensures up to 3 weeks of measurements

The above schedule allows for performing comprehensive scans. G and σ_t (B, HV, θ, φ) are extracted from common data runs, whereas the ion feedback evaluation requires a separate set of data.

High-B Budget Items: FY21

FY21 Budget Request

- LHe (500 L): for one 3-week long run ($6.4k)
- Small components for sensor readouts (cables, connectors, preamp, *etc.*) ($3.3k)
- Undergraduate-student salary (4 weeks): to supplement USC scholarship, for a total of 8 weeks research ($2.4k)
- Travel (Summer 2021 data taking): 6-weeks of travel for 3 USC personnel ($15k)
- Procurement of a 6-μm pore size Photek MAPMT253 ($17.9k)

	100%	80%	60%
LHe and materials for high-B run, JLab	$9.7k	$9.7k	$9.7k
Undergraduate student, USC (50% salary)	$2.4k	$2.4k	$2.4k
Travel, USC	$15.0k	$15.0k	$15.0k
Photek MCP PMT 6 μm pore size, 3× 3 mm^2 pixel	$17.9k	$17.9k	$0k
Total	$45.0k	$45.0k	$27.1k

MCP-PMT/LAPPD^{TM}

ANL: Whitney Armstrong, Sylvester Joosten, Jihee Kim, Ed May, Chao Peng, Bob Wagner, **Junqi Xie**

BNL: Bob Azmoun, **Mickey Chiu**, Alexander Kiselev, Craig Woody

Incom: Camden Ertley, Michael Foley, **Michael Minot**, Mark Popecki

Goal

Adapt LAPPD^{TM} to the EIC requirements: Highly pixelated LAPPD^{TM} working at 2~3 Tesla for mRICH, dRICH, and DIRC, as well as TOF applications.

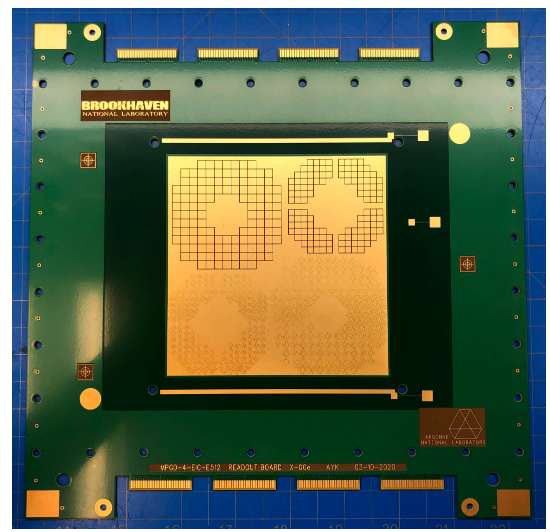
FY20 Report

- Performance of 10-μm pore size MCP-PMT on bench (done, reported Jan. 20)
- Fabrication of Argonne MCP-PMT with integrated R&D and Fermilab beamline test preparation (paused due to COVID-19, restart in August)
- Full engagement of Incom to develop Gen-II LAPPD and Gen-III HRPPD for EIC-PID needs (NP SBIR awarded, in progress)
- Argonne technology transformation to Incom for pixelated LAPPD with high magnetic field tolerance and fast RMS timing (complete)
- Transition from generic MCP-PMT development into project-oriented evaluations of available LAPPDs (in progress)

MCP-PMT: Feb - July 2020 Activities

- Fabrication of MCP-PMT with glass tile and fused silica window (ANL)
  - Capacitively-coupled glass anode tiles prepared
  - Fabrication process paused (COVID-19). Reopen the fabrication lab in August and expect to complete the devices by end of FY20
- GEM based PCB readout board for Fermi beamline test
  - PCB board designed and delivered: pixel pads (3x3mm and 5x5mm) readout for ANL MCP-PMTs (PCB board received in June)
- Fermi Lab (FTBF) beam-line experiment (re-scheduled to Spring 2021)

Glass lower-tile anode with capacitive-coupling pixelated readout.



GEM based PCB board to accommodate Argonne MCP-PMT for FTBF test with pads and zigzag readouts.

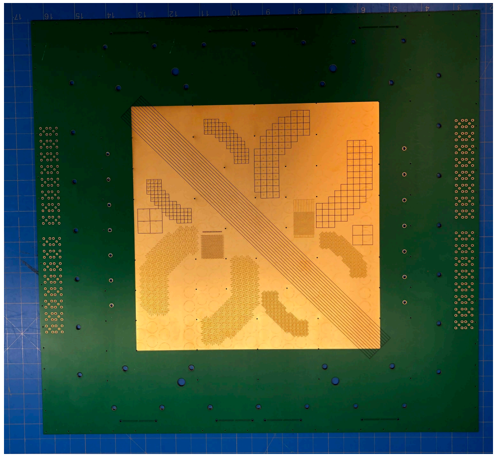
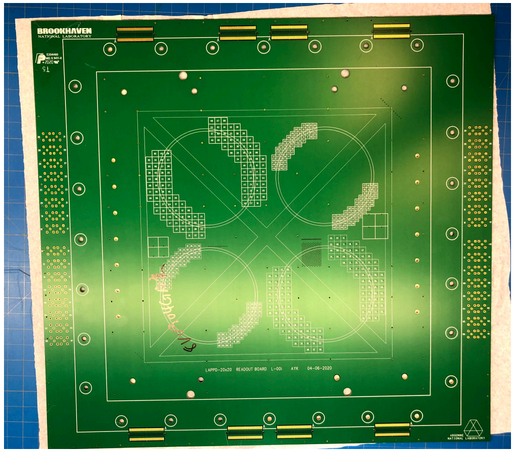
Proposed FTBF Experiment in Spring 2021

Available devices for EIC-PID

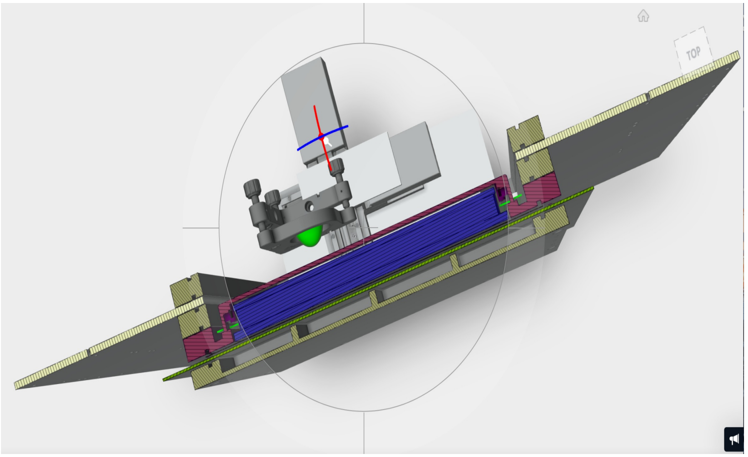
- Two standard Gen-II LAPPDs on loan for free (ready to ship)
- Two ANL 10um MCP-PMT be fabricated
- One high-B optimized Gen-II LAPPD on rent

Proposed beam-line tests (work with mRICH and eRD6 MPGD groups)

- In beam performance validation of Gen II LAPPDs and ANL MCP-PMTs
- mRICH-LAPPD-ToF experiment for combined RICH and TOF test with LAPPD

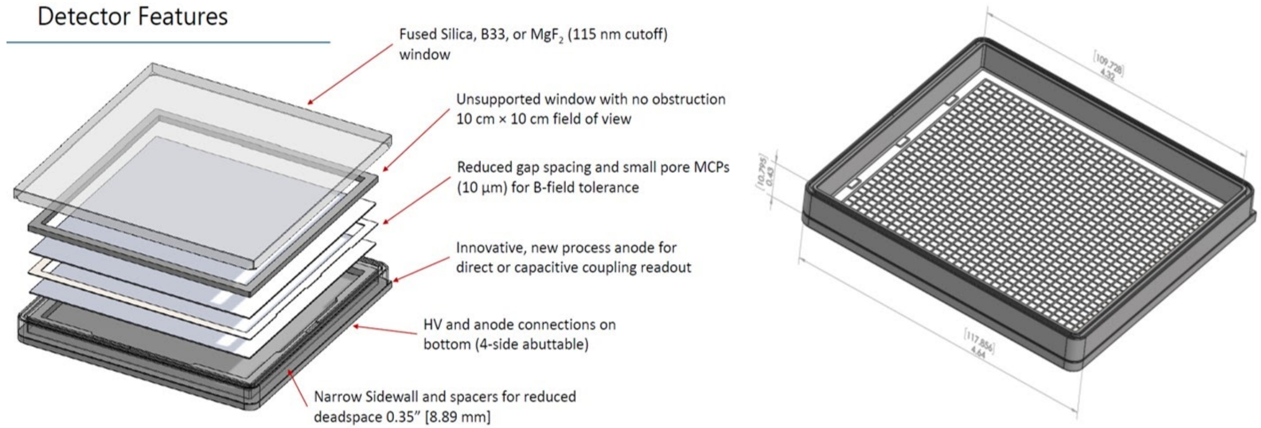
PCB board with pad and zigzag readouts to accommodate 20-cm square LAPPDs



LAPPD setup in beam CAD model

Gen-III LAPPD (HRPPD) Status

SBIR phase I “Large Area Multi-Anode MCP-PMT for High Rate Applications” was awarded.



The results of the ANL R&D study on 10 μm ALD-MCP-PMTs were integrated in the HRPPD design. The sensor is read out using low temperature co-fire ceramic anode (hpDIRC application).

Timeline

- May 2020: Co-fire ceramic anode ordered
- Oct 2020: Co-fire ceramic anode delivery to Incom
- **May 2021:** Expected first HRPPD device delivery to EIC-PID

Proposed tests in FY21

- Performance bench test and magnetic field test as soon as device is available
- Performance tests by EIC-PID groups: will negotiate the delivery of 4 HRPPDs on loan/rent/purchase

FY21 Proposed Activities and Budget Request

FY2021 Proposal Summary

- Bench test of received Gen-II LAPPDs and Gen-III HRPPDs
- Beamline validation of Gen-II LAPPDs with simple pixel readout (Fermilab)
- mRICH-LAPPD-ToF experiment with LAPPD (Fermilab)
- Magnetic field test of an optimized Gen-II LAPPD and one Gen-III HRPPD
- Integration of Gen-II LAPPD with an external pixelated anode and Hawaii SiREAD electronics (if available)
- Gain dependence in magnetic field study on ALD coating
- MCP-PMT/LAPPD after pulsing and ion feedback study

FY2021 budget request

	100%	80%	60%
Staff effort for LAPPDs bench test, beamline preparation and test	$30k	$27k	$25k
Materials for LAPPDs bench test, beamline preparation and test	$10k	$10k	$10k
Staff effort for LAPPDs magnetic field preparation and test	$15k	$13k	$10k
Materials for LAPPDs magnetic field preparation and test	$5k	$5k	$5k
Argonne associate effort for magnetic field, principle R&D study	$25k	$15k	-
BNL travel to Fermilab beamline test, Incom	$17k	$15k	$15k
ANL travel to Incom, meetings	$8k	$5k	$5k
Total	**$110k**	**$90k**	**$70k**

Readout Electronics for eRD14 Prototypes

Marco Contalbrigo – INFN Ferrara
Isar Mostafanezhad - Nalu Scientific
Gary Varner – University of Hawaii

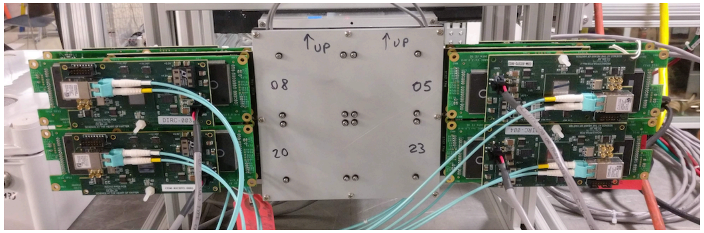
Goals

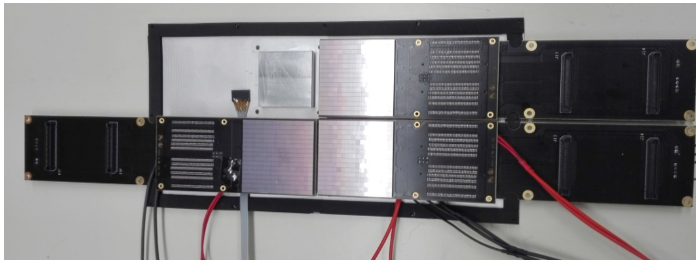
- Develop an integrated suite of readout electronics for the different photo-sensors used for all the Cherenkov detectors and prototypes
- Provide a reference readout system for prototypes performance assessment
- Develop a generic DAQ system compatible with the eRD14 needs
- Test applications with various sensors (including SiPMs)

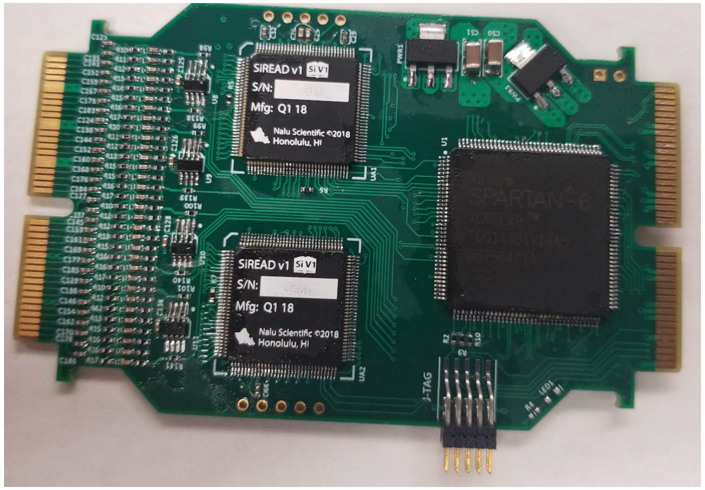
Readout Electronics for eRD14 Prototypes

FY20 Activities

- Development of SiREAD based readout firmware to operate with the SCROD FPGA
- Second generation firmware and improved data throughput for front-end to back-end communication
- Modular and scalable 256-channel building block readout based on the SiREAD ASIC
- Transition from the SiREAD (32-channel) chip to HDSoC (64 channel)
- Development of pulsed laser test benches for detailed characterization

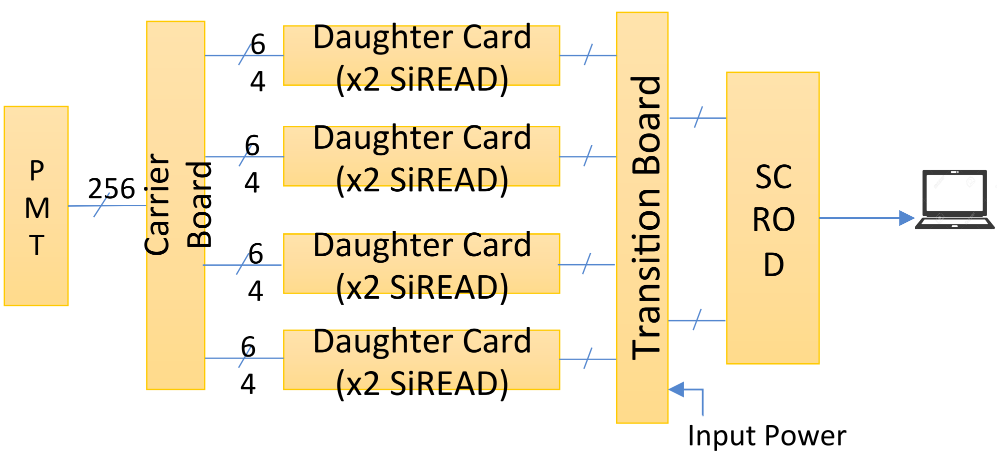






Readout Electronics: FY20 Highlights

- UH hired postdoc (Tripathi), started mid January
- Nalu Scientific team provides in-house FW development, with institutional memory
- UH provides comprehensive bench, environment and picosecond laser/photo-sensor testing
- Immediate push is to get SiREAD version of 256 anode PMT readout working; evaluate performance; design more compact version (HDSoC) (hpDIRC)
- Need for robust firmware development (lesson from Belle II)



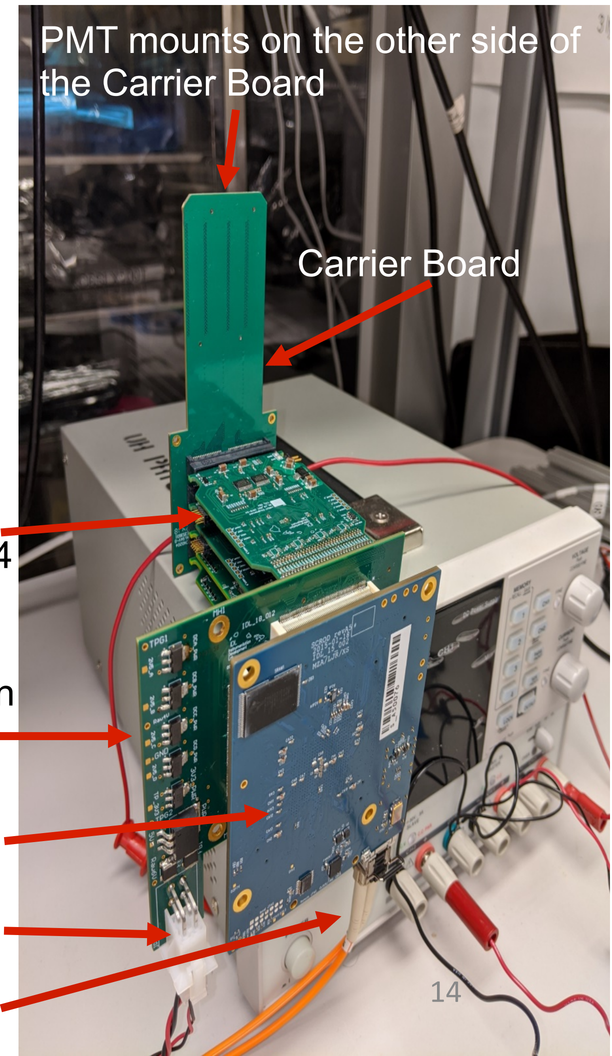
SiREAD DCs x4

Transition Board

SCROD

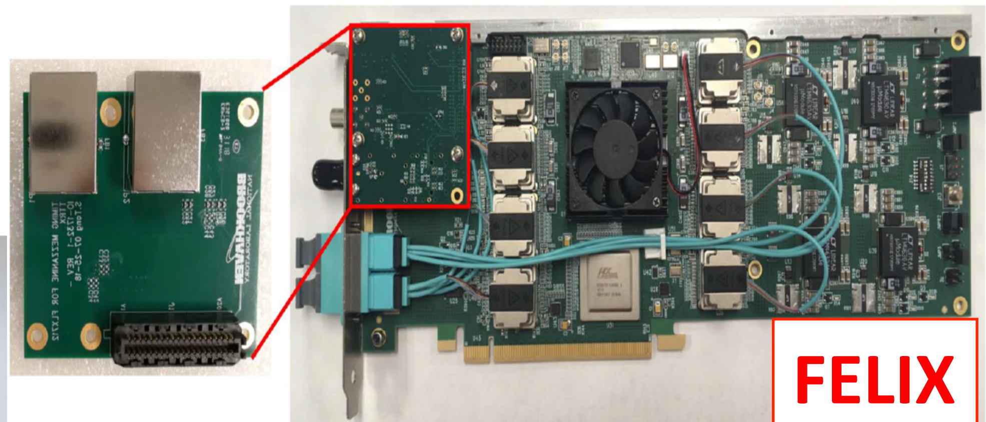
Input power

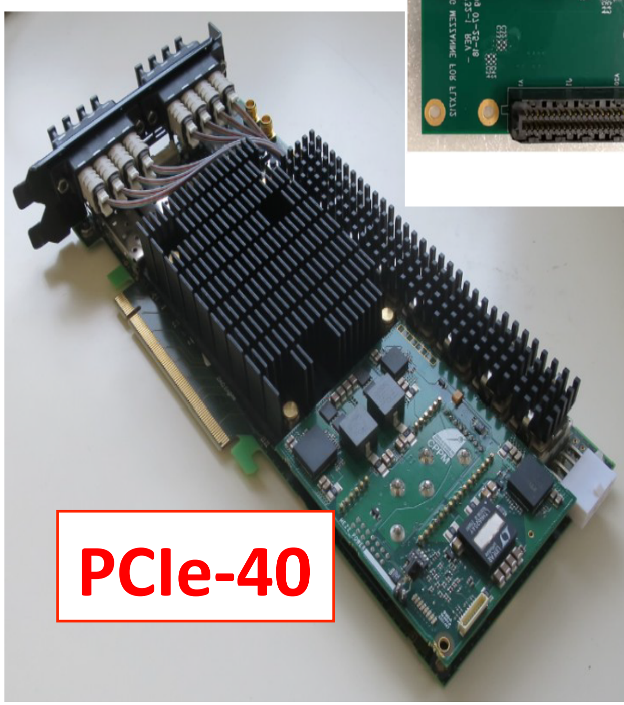
optical gigabit transceiver



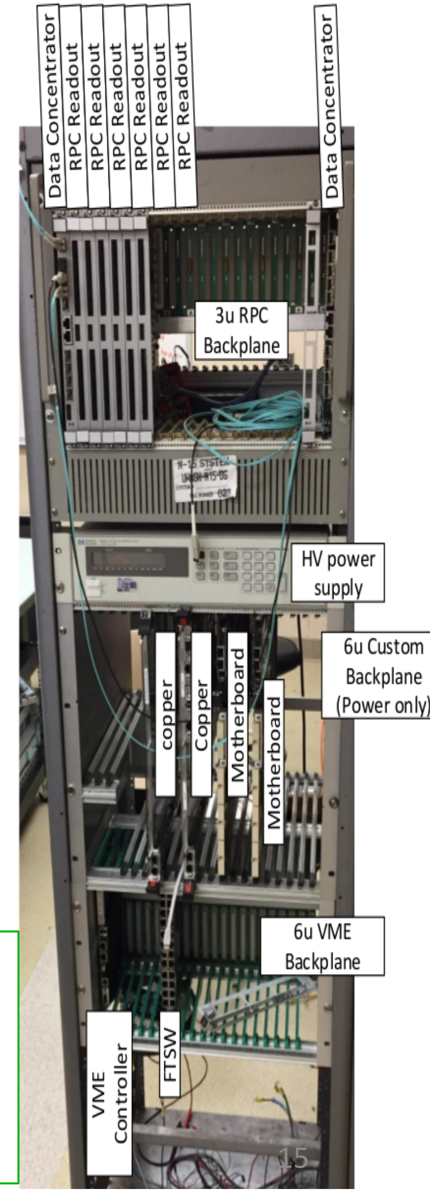
Backend Control/Readout: FY20 Highlights

- Current: JLAB and Belle2link readout as baseline
- Experience with Belle-II DAQ upgrade





Hawaii
Belle II KLM+TOP
DAQ upgrade
Test bench



FY21 Proposed Activities

UH and NALU

- Complete SiREAD-based readout firmware integration with the SCROD FPGA
- Finish second generation firmware development for improved data throughput and front-end to back-end communication
- Integration of the SSP DAQ protocol with the SiREAD front-end chips
- Begin design of photosensor-integral HDSoC ASIC readout

Especially important for hpDIRC FY22 beam test.

INFN

- Development of a portable DAQ system derived from the CLAS12 RICH readout
- Maintenance and operation of reference electronics and pulsed-laser test stations

FY21 Budget request

	100%	80%	60%
Postdoc, Hawaii, 12 months (Shivang Tripathi)	\$60k	\$60k	\$58.8k
Grad Student, Hawaii, 0-9 months (Ethan Lee)	\$38k	\$15k	
Postdoc, INFN, 2 month (Luca Barion)	\$7k	\$7k	\$7k
Postdoc, INFN, 4 month (Aram Movsisyan)	\$13k	\$13k	\$13k
Components, INFN	\$13k	\$5k	
Travel INFN	\$2k	\$2k	
Total	\$133k	\$102k	\$78.8k

Yearly contract with Nalu Scientific for engineering support.

Four Year R&D Plan

- FY2020: complete SiREAD-based MA-PMT readout (on schedule)
- FY2021: MCP-PMT readout for DIRC prototype (beamtest) (funding request)
- FY2022: Integrated-cooling Si-PM readout (activities begin in FY20, dRICH slides)
- FY2023: Triggerless DAQ readout demonstrator (on schedule)

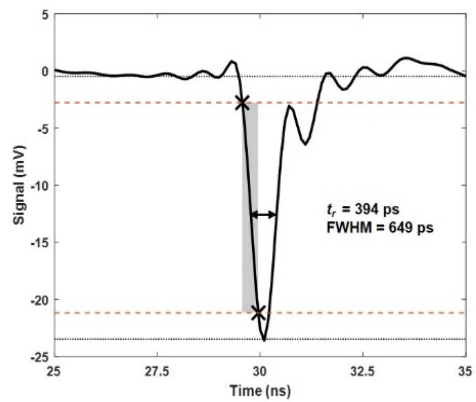
Backup Slides: LAPPD

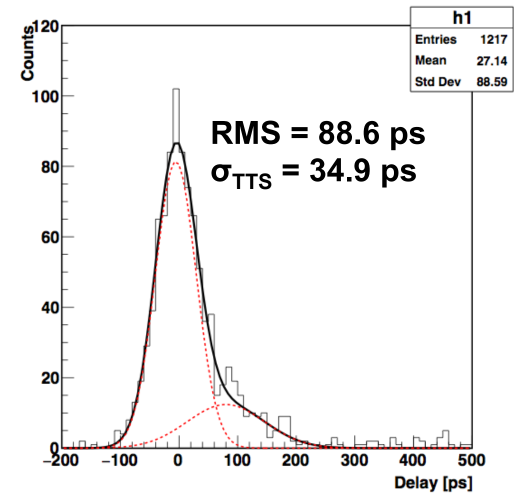
Bench test summary of Argonne 10 μm ALD-MCP-PMTs

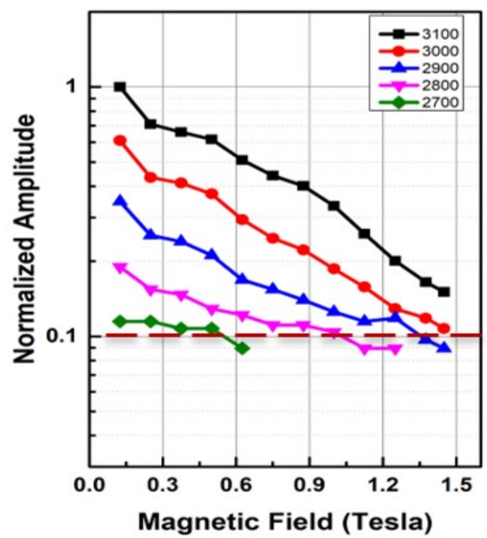
ANL Version 4 10 μm MCP-PMT with reduced spacing

MCP	Pore size	10 μm
	Length to diameter ratio (L/d)	60:1
	Thickness	0.6 mm
	Open area ratio	70 %
	Bias angle	13°
Detector geometry	Window thickness	2.75 mm
	Spacing 1	2.25 mm
	Spacing 2	0.7 mm
	Spacing 3	1.1 mm
	Shims	0.3 mm
	Tile base thickness	2.75 mm
MCP-PMT stack	Internal stack height	**5.55 mm**
	Total stack height	11.05 mm

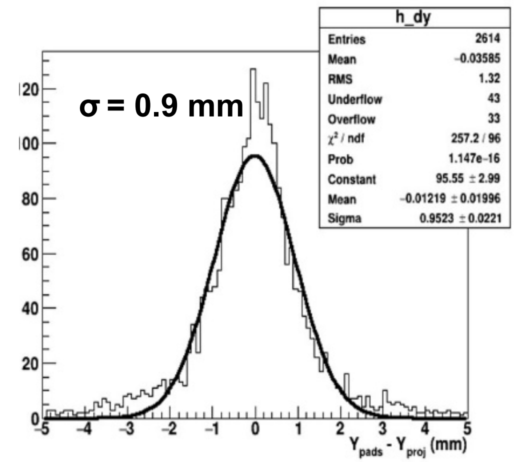
Gain Characteristic	Gain	2.0×10^{7}
Time Characteristic	Rise time	**394 ps**
	TTS RMS time resolution	88.6 ps
	TTS resolution	35 ps
Magnetic Field	Magnetic field tolerance	**Over 1.5 T**



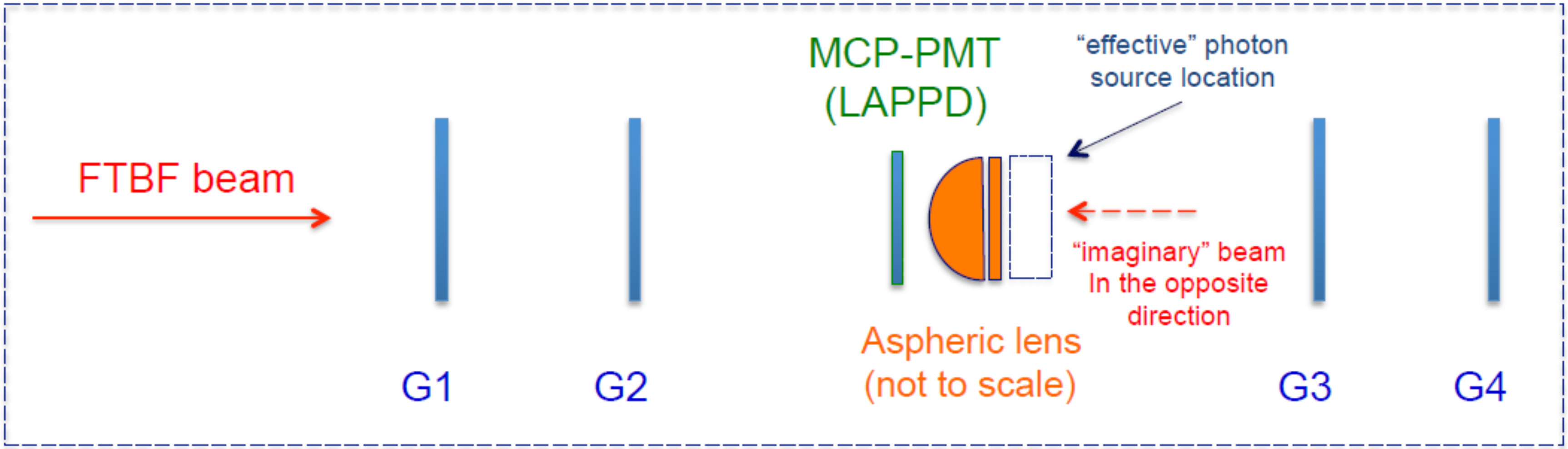




3mm x 3 mm pixel



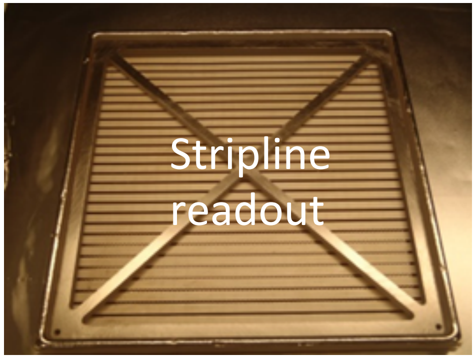
Fermilab beamline experiment plan

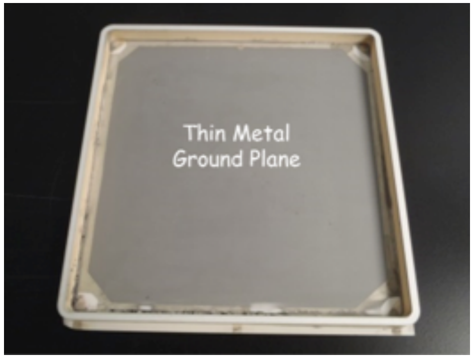


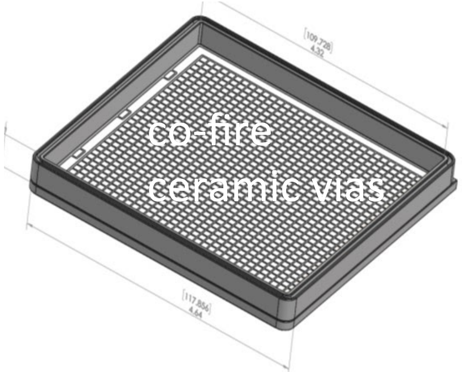
- GEM tracker (2x2 100x100 mm^2 COMPASS 2D chambers)
- *Either* Argonne MCP-PMT *or* Incom LAPPD (only 128 DRS4 channels)
- Small thick fused silica aspheric lens from Edmund Optics:
  - MCP-MPT: #87-975, 12.5 mm diameter, 10.0 mm effective focal length, 8.0 mm central thickness
  - LAPPD : #67-265, 25.0 mm diameter, 20.0 mm effective focal length, 14.0 mm central thickness
- *Backward reflection of Cherenkov light* on the rear flat lens surface
  - A single ~$400 off the shelf optical component ...
  - ... with minimum of required modifications (the ground side needs to be black painted though)
  - "Perfect" optics for all photons, which do not hit the side surface (those will be absorbed): a single refraction of a mirror-imaged Cherenkov light cone + refraction on the MCP-PMT window; no spherical aberrations and no parasitic reflections inside the lens

Difference between LAPPD generations

Feature	Gen I LAPPD	Gen II LAPPD	Gen III HRPPD
Application	TOF	TOF, RICH	hpDIRC, RICH
Detector Size	20 cm × 20 cm	20 cm × 20 cm, 10 cm x 10 cm	10 cm × 10 cm
UHV Package Design	X-Spacers window support -> creates dead zones	X-Spacers window support -> creates dead zones	X-Spacer free -> large effective area
Window	Fused Silica, B33 Glass	Fused Silica, B33 Glass	UV Fused Silica, MgF_2
λ Sensitivity	200 (300 for B33) - 600 nm	200 (300 for B33) - 600 nm	115 - 400 nm
Photocathode	Bialkali	Bialkali	UV optimized Bialkali
MCP Pore Size	20 µm	20 µm & 10 µm	10 µm
MCP Stack	Without B-Field Optimized	Without/with B-Field Optimized	B-Field Optimized
Anode	Direct readout of thick film strips	Capacitive readout with application specific patterned anode	High density pixelated anode with direct or capacitive readout
Connections	Through Frit Seal -> 2 side abuttable	Through Frit Seal -> 2 side abuttable	Through anode -> 4 side abuttable with minimum dead space

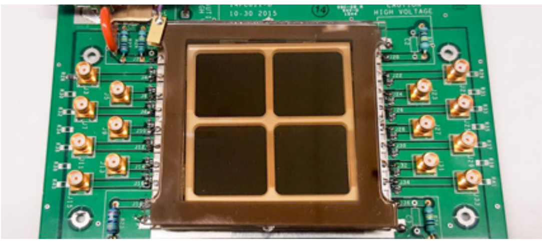




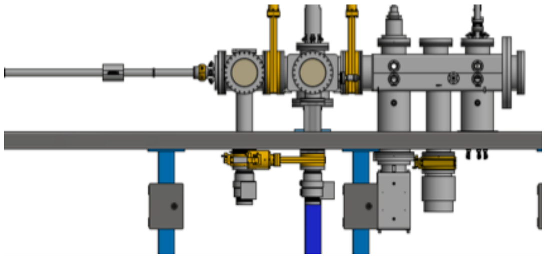


ANL Pixelated MCP-PMT Program

Fast light sensors to enable RICH/DIRC in areas with high magnetic fields.



- High-resolution (spacial+timing) sensors that can work in strong magnetic fields important for all RICH/DIRC designs.



- In-house program to develop and construct pixelated 10x10cm MCP-PMTs, currently building new R&D fabrication facility.

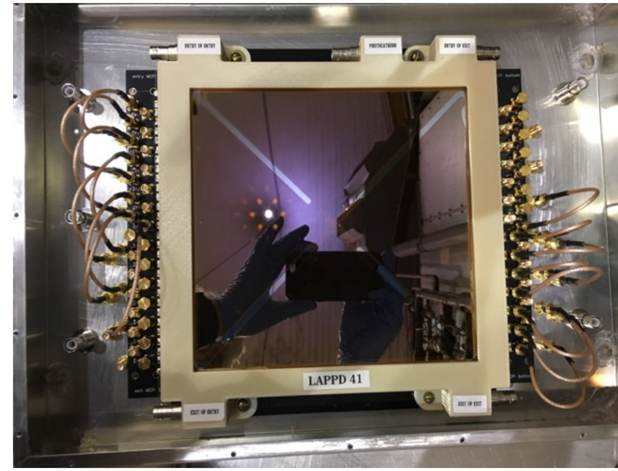
- Strong relation through SBIR with Incom for (affordable!) commercialization of our technology, and with Nalu Scientific to develop dedicated readout ASIC.

Cherenkov test of LAPPD at JLab Hall C

Received LAPPD#41: Gen I

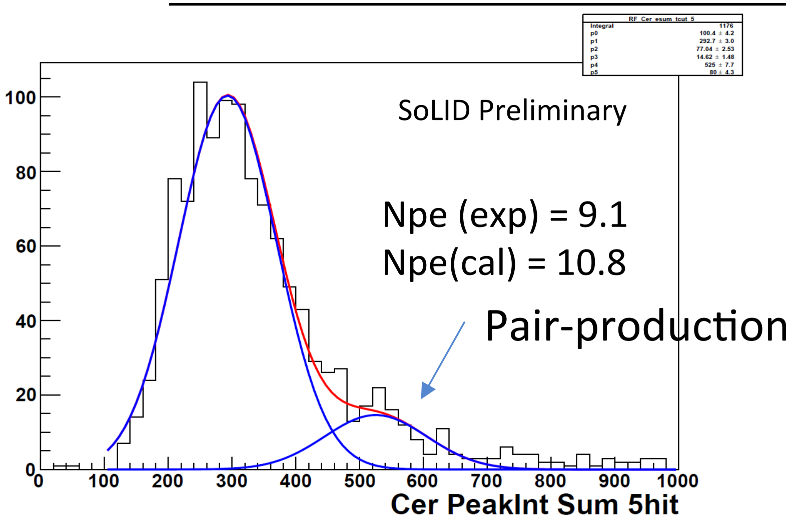
High rate background environment

Window material	Fused silica
Readout anode	Inside stripline
Quantum Efficiency	Mean: 7.3%, Maximum: 11%
Gain	5.4×10^{6} with MCPs @ 975V
Time resolution	56 ps

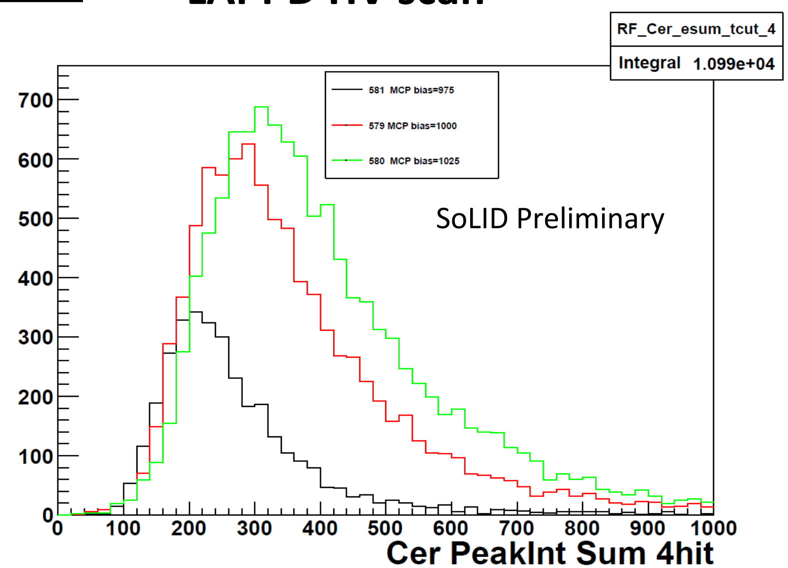


Results

Event cut	**MaPMT**	**LAPPD**
Scin+ calo	0.81 M	7.1 M
Cher + scin + calo	0.056 M	0.16 M
Detection efficiency	**6.9%**	**2.2%**



LAPPD HV scan



JLab Hall C test shows that the LAPPD identified single particle events and pair-production events , might work at Hall C high rate environment. Require high QE, pixelated LAPPD for further validation.

Sep 2019 Committee Recommendation on Tests of LAPPDs

The committee believes that the LAPPD MCP effort has a long road ahead before it can be accepted as a baseline detector choice for inclusion in the TDR in 2023. To be included in the TDR requires that the consortium provides detectors with 3mm pixels, 10μm MCP holes to allow 1.5T operation and have small dead space around the boundary. The only suitable LAPPD devices for RICH application seem to be the Gen-III detectors, scheduled for 2021 delivery.

There is a number of tests required before these detectors can be placed in the DIRC prototype. A possible list includes:

- Provide a prototype to the Hawaii group to allow tests with the SiREAD electronics.
- Determine the S/N ratio and reliable voltage range operation. Measure timing resolution as a function of S/N ratio with an appropriate amplifier.
- Determine cross-talk to neighboring pixels for capacitively coupled pixels. Two amplifiers are needed to do this.
- Determine charge sharing to neighboring pixels for capacitively coupled pixels, with and without magnetic field. Two amplifiers are needed to do this.
- Determine ion feedback as function of voltage for tubes with and without ALD coating.
- Determine photocathode deterioration as a function of total anode charge and general tube operation instability in case of large charges.
- Make a 2D scan of these tubes to determine possible inefficiencies around the edges. The SiREAD electronics is needed to do this.

It is also strongly suggested to distribute four LAPPD prototypes to several groups to get a common understanding of this device. This means one tube to JLAB, one tube at ANL, one to Lehmann and one tube to Hawaii.

Actions after recommendations

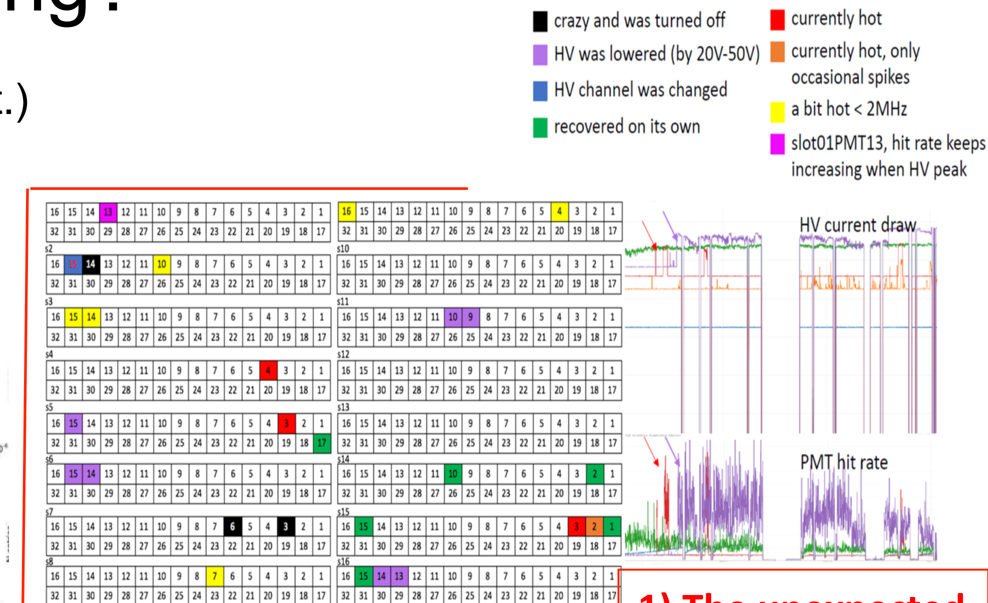
- Transition from generic MCP-PMT development into project-oriented evaluations of available LAPPDs.
- Full engagement of Incom to develop Gen-II LAPPD and Gen-III HRPPD for EIC-PID needs
- Negotiation with Incom for fast bench test and in beam proof-of-concept test to validate available LAPPDs.
- Extended communication/work within and out of eRD14 for full LAPPD tests.

- The 1-year delay of DIRC beamline test provides more feasibility for HRPPD to catch up hpDIRC beamline test.
- We strongly believe capacitively coupled LAPPD with Argonne full glass design would be suitable for mRICH and dRICH applications.
- Proof-of-concept validation of Incom Gen-II LAPPDs and Argonne full glass MCP-PMT on bench as well as in beamline are being investigated before the delivery of HRPPD in May 2021.
- Argonne is currently building new R&D fabrication facility under ANL internal funding support to enable in-house pixelated 10x10cm MCP-PMT construction with ANL full glass design for photosensor and detector prototype development to support EIC.

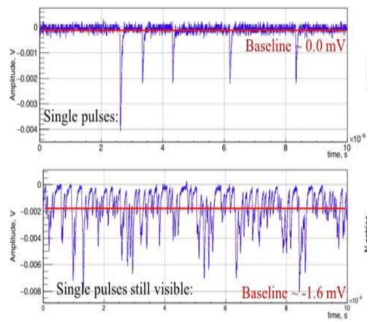
Backup Slides: Electronics

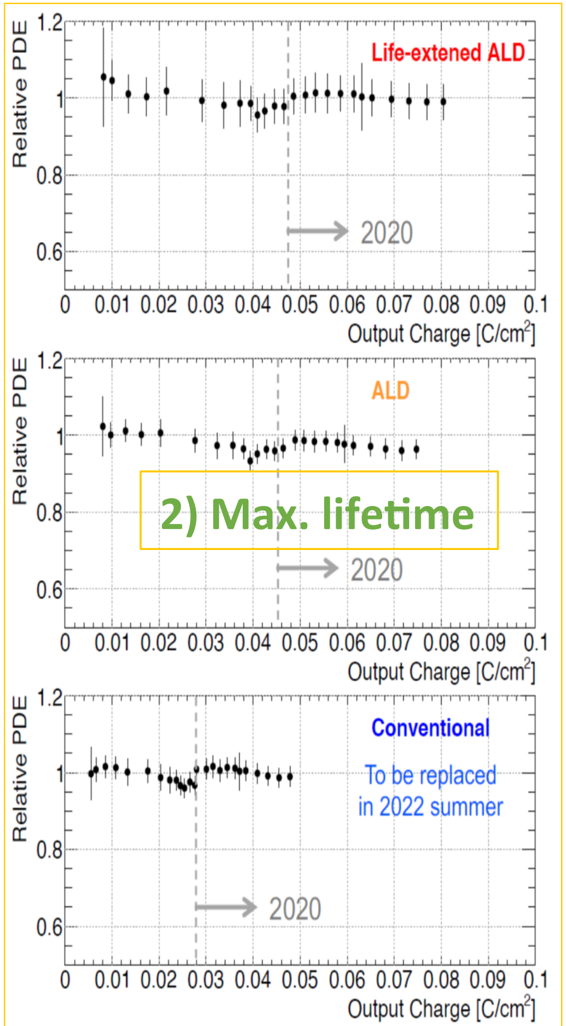
Why waveform sampling?

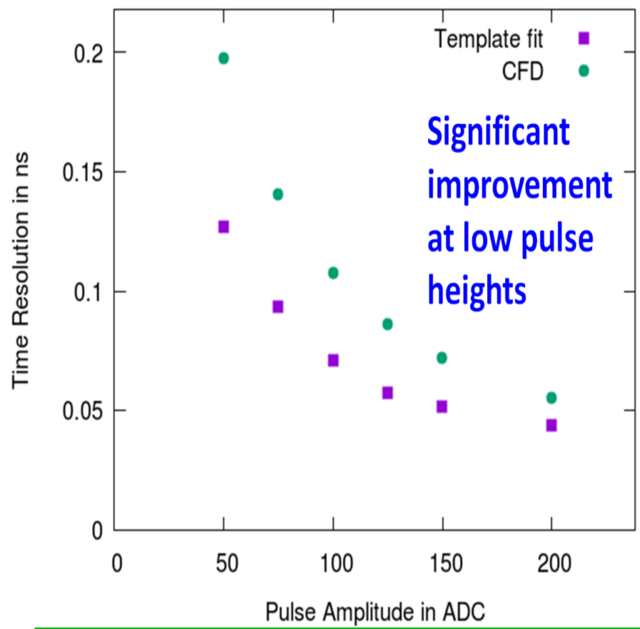
- CF: Amp+Disc+TDC (often TOT for ampl. Est.)
- 3 reasons (besides cost)

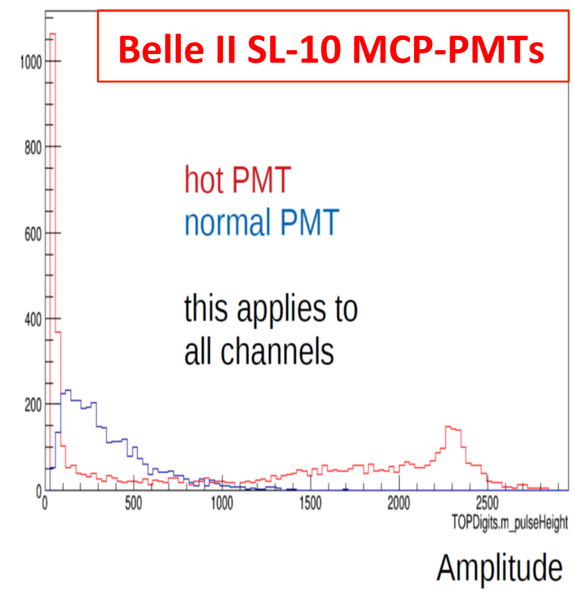


1) The unexpected



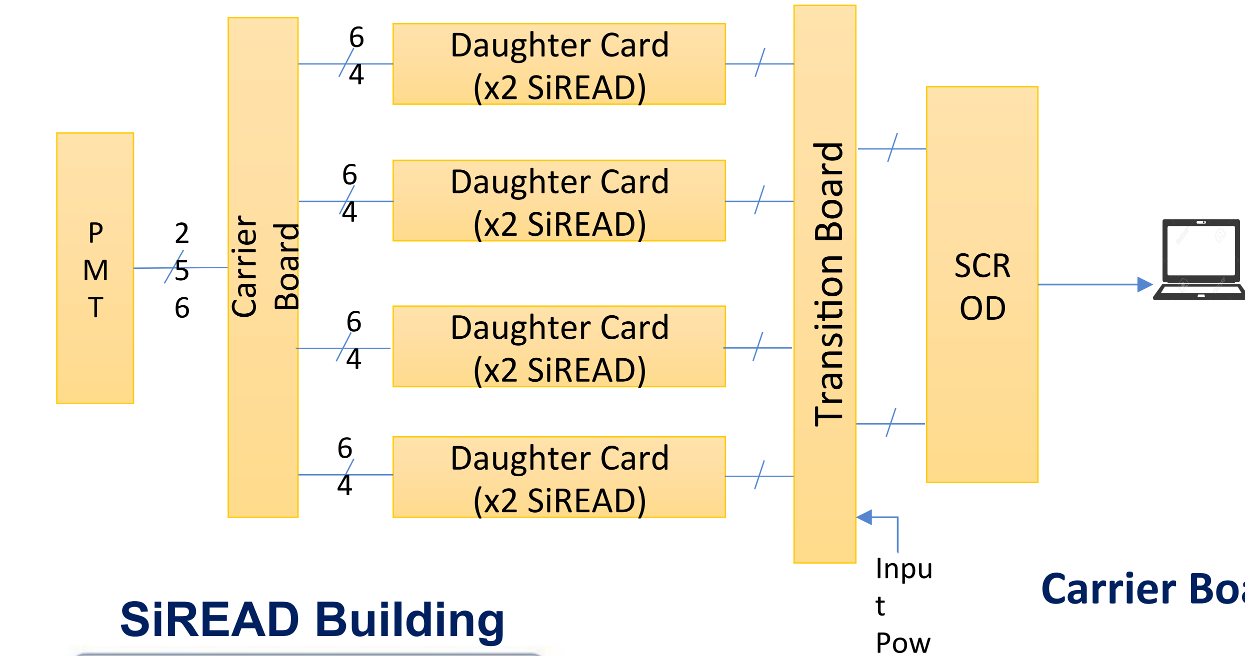




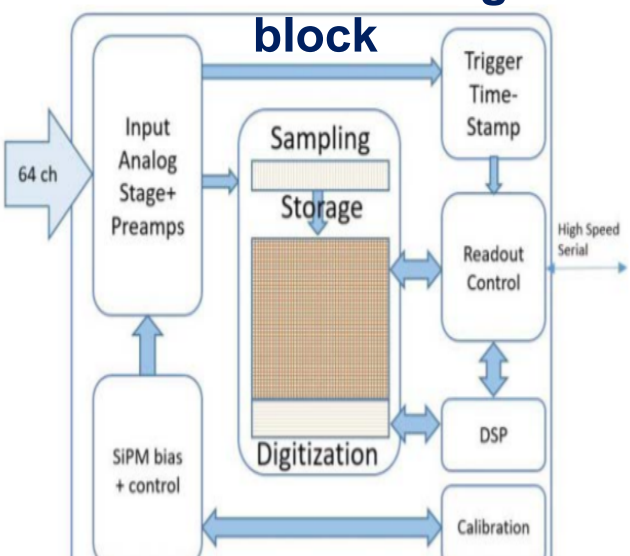


3) Optimizing (timing) performance

Readout Electronics: FY20 Highlights

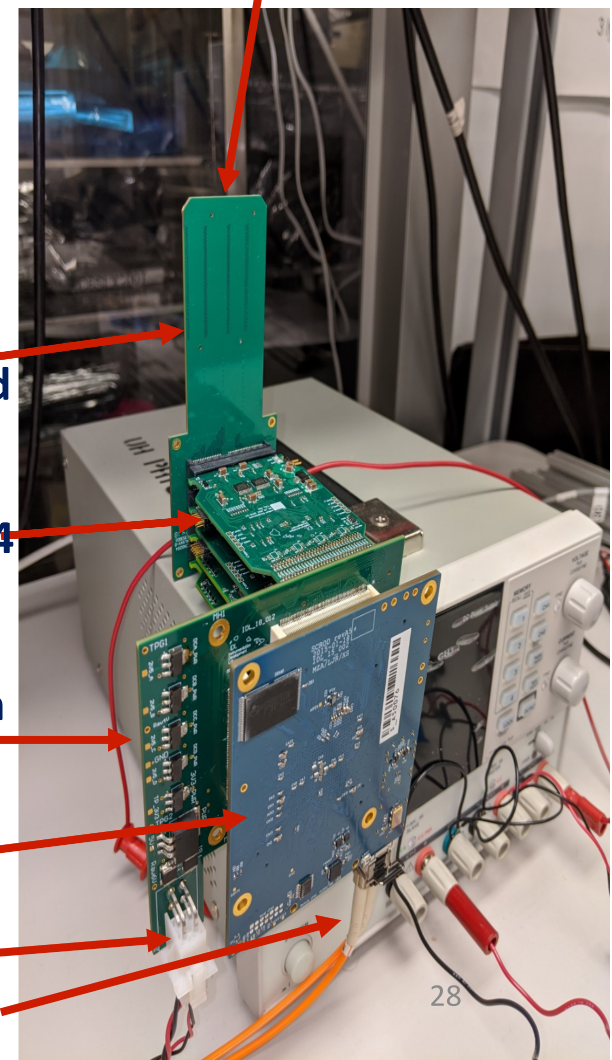


SiREAD Building block



Isar *et al.*, IEEE NSS-2018

SiREAD Parameter	Specifications
Channels	32
Sampling rate	1 GSa/s
Storage samples/ch	4096
Est. Analog BW	0.7-1.1 GHz
RMS voltage noise	1.3 mV
Signal voltage range	2.1 V
ADC on chip	12 bits
Readout	Serial LVDS
Power consumption	20-40 mW/ch



Readout Electronics for Detector Prototypes

Sep2019 Committee Recommendation:

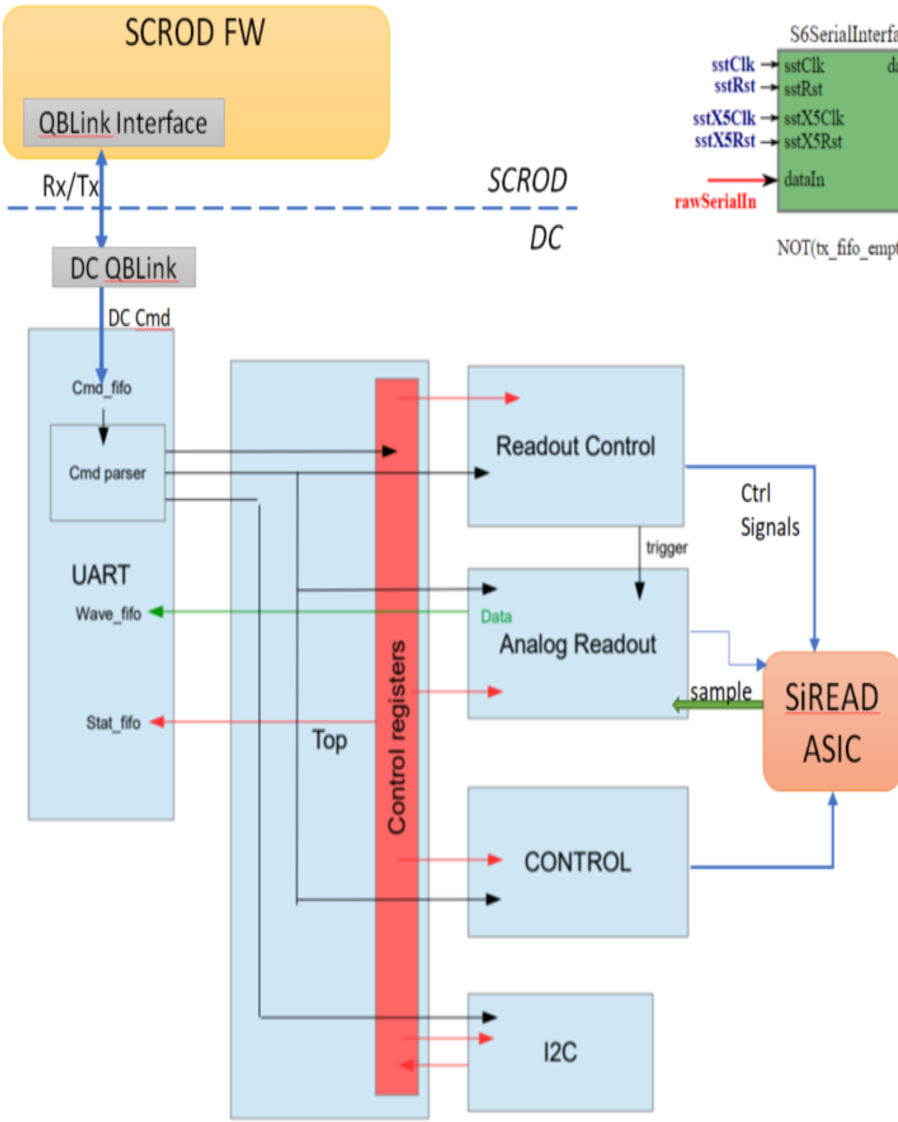
In general, the electronics plan seems reasonable and, in some ways, advanced beyond the state of the photosensors for the different detectors, where there is no clear baseline.

Primary among the worries for the committee, is the power required to achieve the performance, especially in the case of the DIRC and then the mass and radiation length of the cooling system(s) required to deal with the associated heat.

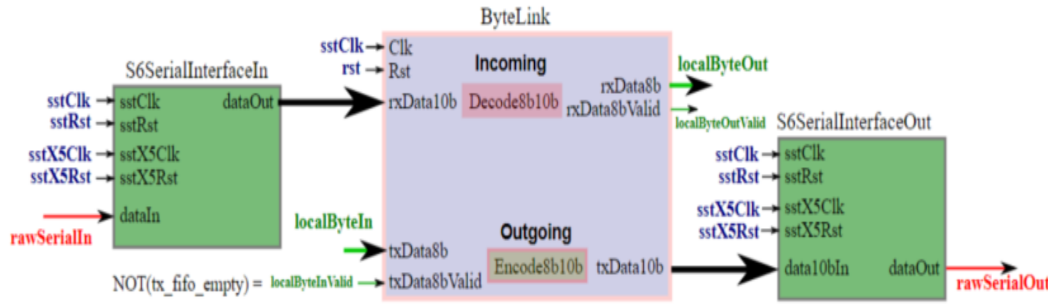
…it would seem useful for each detector sub-consortium to develop, in concert with the electronics group, a crude estimate of the total power required for a strawman detector and then work out a plausible cooling scheme for that power (study ongoing for mRICH).

…it is suggested to concentrate on the near-term development of the front-end and delay the back-end work by another quarter. We encourage the group to interact face-to-face to make the estimates suggested above. There may be alternatives to a waveform sampler but a more detailed estimate of the power issues is called for.

SiREAD DC Firmware



Quad Byte line (QBlink)



- Communication links between the SCROD and DCs is maintained using **QBLink**
- **Readout Control:** starts and stops acquisitions and handles triggers
- **Analog Readout:** handles the control of the SiREAD ASIC including write/read location and the actual readout
- **CONTROL:** writes the analog register

Electronics – Specifics

Requirements

- Need to read out several photosensors (MaPMTs, MCP-PMTs, and SiPMs) with similar sensor and pixel size (16x16 array of 3 mm pixels)
    - DIRC also requires good timing (<100 ps)
- Goal is to have common front end electronics with good timing that can be used for all sensors and detectors (mRICH, dRICH, DIRC)

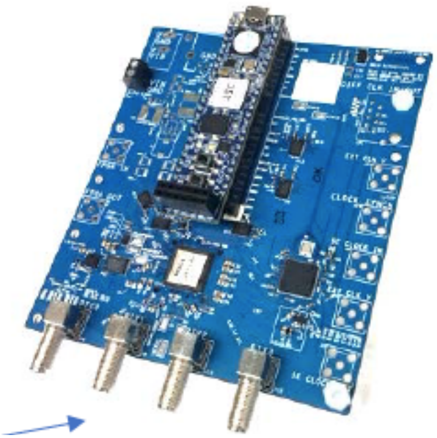
Implementation

- The Maroc-based CLAS12 front end has been adapted to 3 mm pixels and already used for the first two mRICH beam tests (next slide)
    - Maroc is not a universal long-term solution due to its poor timing
- After initial studies using TARGETX chips, the front end have now switched to the SiREAD ASIC. This can be used for all EIC PID detectors and sensors.

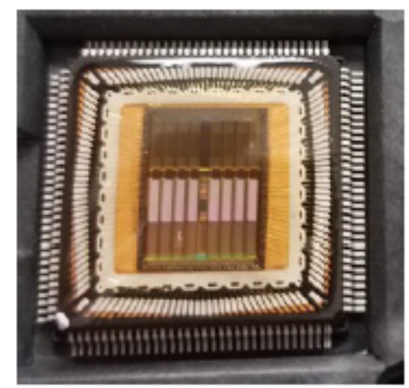
Nalu's SoC-ASIC Portfolio

Nalu Scientific
Data Acquisition Systems

Project	Sampling Frequency (GHz)	Input BW (GHz)	Buffer Length (Samples)	Number of Channels	Timing Resolution (ps)	Available Date
ASoC	3-5	0.8	32k	8	35	Rev 2 avail
SiREAD	1-3	0.6	4k	64	80-120	Rev 1 avail
AARDVARC	6-10	2.5	32k	4-8	4-8	Rev 2 avail
AODS	1-2	1	8k	1-4	100-200	Nov 2019



- **ASoC**: Analog to digital converter System-on-Chip
  - Rev 1 under test – **Funded Phase II - Eval card available**
- **SiREAD**: SiPM specialized readout chip with bias and control
  - Rev 1 under test



- **AARDVARC**: Variable rate readout chip for fast timing and low deadtime
  - Rev 1 under test – **Funded Phase II**

All chips, are designed with commercial grade tools and licenses and can be sold once commercialized.